

A COMPARATIVE STUDY ON THE EXERGOCOECONOMIC ANALYSIS OF TEXTILE DRYERS USING SPECOC METHOD

SPECOC YÖNTEMİNİN KULLANILMASI İLE TEKSTİL KURUTUCULARININ EKSERGOCOEKONOMİK ANALİZİ ÜZERİNE KARŞILAŞTIRMALI BİR ÇALIŞMA

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ABSTRACT

This study reveals the exergoeconomic analysis of stenters by using Specific Exergy Costing (SPECOC) method. The cost balances and auxiliary thermoeconomic relations were developed for direct gas heated (DGHS) and hot oil heated (HOHS) stenters by the application of the control volume models. The exergy cost of the evaporation of water was selected to be the main parameter. It was shown that the falling-rate period of drying led to the highest exergy costs, while exergy costs varied between 0.19 US\$/GJ and 0.59 US\$/GJ depending on the drying periods. Increasing the exhaust air humidity ratio and the residual moisture content of the fabric outlet decreased the exergy costs linearly.

Key Words: Exergoeconomic analysis, Specific exergy costing method (SPECOC), Textile drying, Stenter.

ÖZET

Bu çalışmada ramözlerin eksergoekonomik analizi, Özgül Ekserji Maliyeti (SPECOC) yönteminin kullanılmasıyla açıklanmaktadır. Direkt doğal gaz ısıtmalı (DGHS) ve kızgın yağ ısıtmalı (HOHS) ramözler için maliyet denklikleri ve yardımcı termoekonomik bağıntılar geliştirilmiştir. Suyun buharlaştırılması için gerekli ekserji maliyeti temel parametre olarak seçilmiştir. Ekserji maliyetleri kurutma periyotlarına bağlı olarak 0.19 US\$/GJ ile 0.59 US\$/GJ arasında değişmektedir. Kurutmanın azalan hız periyodunun en yüksek ekserji maliyetine neden olduğu gösterilmiştir. Atık hava nemi ve kumaş çıkış neminin artırılması ile ekserji maliyetleri doğrusal olarak azalmaktadır.

Anahtar Kelimeler: Eksergoekonomik analiz, Özgül ekserji maliyeti metodu (SPECOC), Tekstil kurutması, Ramöz.

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1. INTRODUCTION

The textile industry uses large amounts of energy (1, 2), thus the investigation of the cost formation and flow in the textile processes is of great importance. Since drying is the most energy-intensive unit operation in textile finishing mills, an exergoeconomic analysis was conducted to convective drying processes.

Exergoeconomics is the combination of exergy and cost analyses in order to ensure a proper approach for understanding the cost formation process in thermal systems. Thus it

can be considered as exergy-aided cost-reduction method (3). Exergy analysis usually predicts the thermodynamic performance of an energy system and the efficiency of the system components by accurately quantifying the entropy-generation of the components. Furthermore, exergoeconomic analysis estimates the unit cost of products such as electricity and steam and quantifies monetary loss due to irreversibility (4). The objective of exergoeconomic analysis might be the calculation of the costs of each product generated by a

system; the understanding of the cost flows in the systems, the optimization of specific variables or the optimization of the overall system (5).

Systems should be analyzed exergetically in order to perform exergoeconomic analysis. Exergy is the work potential of a system in a specified environment and represents the maximum amount of useful work that can be obtained as the system is brought to equilibrium with the environment (6).

There are several exergoeconomic approaches in the literature. Among them, the SPECOC method (7, 8) was used in this study. The method presents a general, systematic, simple and unambiguous approach for developing the exergetic efficiencies of thermal systems and their sub-components. Additionally it provides general criteria for developing auxiliary costing equations associated with any system with a higher acceptance ratio (9). This method is based on specific exergies and costs per exergy unit, exergetic efficiencies and the auxiliary costing equations for components of thermal systems (10). The main steps of the method are (i) the identification of exergy streams, (ii) definition of fuel and product and (iii) formation of cost balance and auxiliary equations (9).

Although the SPECOC method has been applied to some thermal systems (10-13), it has been used in the textile dryers based on the actual operational data for the first time to the best of the authors' knowledge. This was the prime motivation behind performing the present contribution. The detailed system description and exergy analyses of stenters have been given in the previous studies of the authors (14, 15), who have extended their

study by the exergoeconomic modelling.

2. EXERGOECONOMIC ANALYSIS

The specific flow exergy is determined as

$$ex = (h - h_0) - T_0(s - s_0) \quad (1)$$

where h is the specific enthalpy, s is the specific entropy, and the subscript zero indicates properties at the reference (dead) state.

The exergy rate is expressed as

$$\dot{Ex} = \dot{m} \cdot ex \quad (2)$$

The cost rate associated with the exergy transfers by materials streams, power and heat transfer rates can be written as follows, respectively:

$$\dot{C}_i = c_i \dot{Ex}_i \quad (3)$$

$$\dot{C}_e = c_e \dot{Ex}_e \quad (4)$$

$$\dot{C}_w = c_w \dot{W} \quad (5)$$

$$\dot{C}_q = c_q \dot{Ex}_q \quad (6)$$

The cost balance of a system can be written as (3):

$$\sum_e (c_e \dot{Ex}_e)_k + c_{w,k} \dot{W}_k = c_q \dot{Ex}_q + \sum_i (c_i \dot{Ex}_i)_k + \dot{Z}_k \quad (7)$$

where \dot{Ex}_i , \dot{Ex}_e , c_i and c_e are the exergy rates and exergy costs of the streams entering and leaving the control volume respectively. The term \dot{Z}_k is the annualized cost rate of the equipment.

In the exergoeconomic analysis of stenters, the control volume models of DGHS and HOHS presented in Figures 1 and 2 (14) were applied to the analysis and, the cost rate balances and auxiliary thermoeconomic relations were formed for each sub-component at steady-state operation. These equations for DGHS and HOHS are listed in Tables 1 and 2, respectively. Annualized cost rates of the sub-components of DGHS and HOHS are given in Table 3.

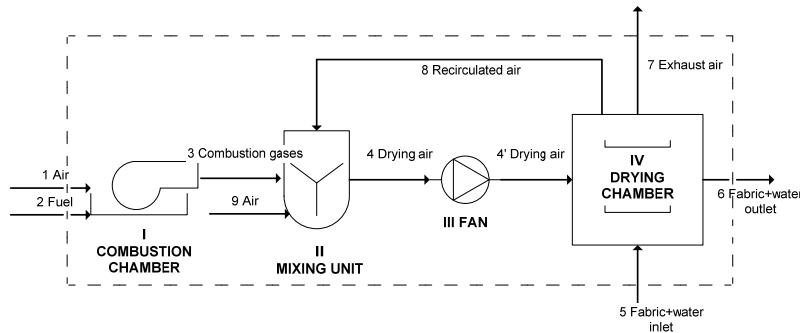


Figure 1. Control volume of the direct gas heated stenter (DGHS) (14)

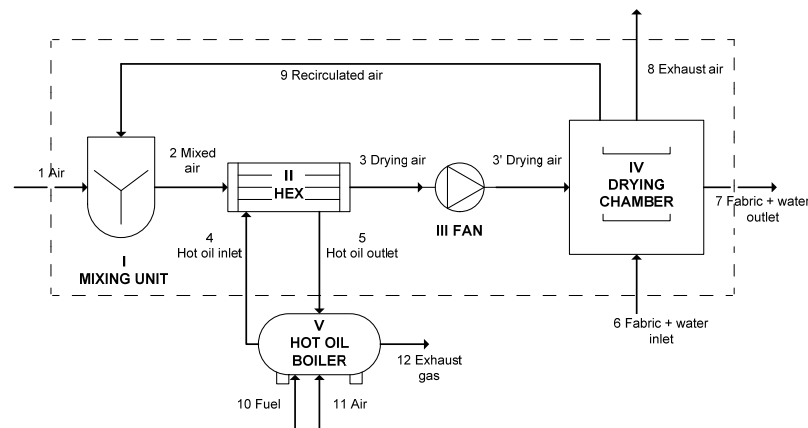


Figure 2. Control volume of the hot oil heated stenter (HOHS) (14)

Table 1. Cost rate balances and auxiliary thermoeconomic relations for DGHS

Cost rate balance	Auxiliary relations
I Combustion chamber $\dot{C}_1 + \dot{C}_2 + \dot{Z}_I = \dot{C}_3$ (8)	$c_1 = 0$ (8a)
II Mixing unit $\dot{C}_3 + \dot{C}_8 + \dot{C}_9 = \dot{C}_4$ (9)	$c_9 = 0$ (9a)
III Fans $\dot{C}_4 + \dot{C}_w + \dot{Z}_{III} = \dot{C}_{4'}$ (10)	
IV Drying chamber $\dot{C}_{4'} + \dot{C}_5 + \dot{Z}_{IV} = \dot{C}_6 + c_8(\dot{E}x_8 + \dot{E}x_7 - \dot{E}x_{ev}) + c_{ev}\dot{E}x_{ev} + \dot{C}_q$ (11)	$c_5 = 0$ (11a) $c_{4'} = c_7 = c_8 = c_q$ (11b)

Table 2. Cost rate balances and auxiliary thermoeconomic relations for HOHS

Cost rate balance	Auxiliary relations
I Mixing unit $\dot{C}_1 + \dot{C}_9 = \dot{C}_2$ (12)	$c_1 = 0$ (12a)
II Heat exchanger $\dot{C}_2 + \dot{C}_4 + \dot{Z}_{II} = \dot{C}_3 + \dot{C}_5$ (13)	$c_4 = c_5$ (13a)
III Fans $\dot{C}_3 + \dot{C}_w + \dot{Z}_{III} = \dot{C}_{3'}$ (14)	
IV Drying chamber $\dot{C}_{3'} + \dot{C}_6 + \dot{Z}_{IV} = \dot{C}_7 + c_9(\dot{E}x_9 + \dot{E}x_8 - \dot{E}x_{ev}) + c_{ev}\dot{E}x_{ev} + \dot{C}_q$ (15)	$c_6 = 0$ (15a) $c_{3'} = c_8 = c_9 = c_q$ (15b)
V Hot oil boiler $\dot{C}_{10} + \dot{C}_{11} + \dot{C}_5 + \dot{Z}_V = \dot{C}_4 + \dot{C}_{12} + \dot{C}_q$ (16)	$c_{11} = 0$ (16a) $c_5 = c_4$ (16b) $c_{10} = c_{12} = c_q$ (16c)

Table 3. Annualized cost rates of stenters

		\dot{Z} (US\$/s)
DGHS	Combustion chamber	0.0026
	Mixing unit	-
	Fans	0.0023
	Drying chambers	0.0139
HOHS	Mixing unit	-
	Heat exchanger	0.0032
	Fans	0.0023
	Drying chambers	0.0132
	Hot oil boiler	0.0032

In the exergoeconomic analysis of drying by using the SPECO, the target exergy costing was selected to be the exergy costing of the water

evaporated. Hence, as shown in Eqs. 11 and 15, the exergy rate of the water evaporated was indicated as a separate constituent. The exergy

costing values of each stenter type were calculated and discussed. There are few studies on the use of the SPECO method in exergoeconomics,

and to the best of the authors' knowledge, exergoeconomic analysis of textile dryers is carried out for the first time in the open literature.

3. RESULTS AND DISCUSSION

The main product in drying processes is the water vapor although the water vapor is thrown out by exhaust air. The exergy cost required for the evaporation of the water content in the fabric is of great importance since the whole energy is utilized for this aim in drying processes. On this account, exergy costs of the water evaporated was emphasized and the models presented in Tables I and II were applied to the overall system to calculate the exergy costs and their variation depending on the primary process parameters.

Figure 3 illustrates the exergy costs of water vapor evaporated, while the specific cost associated with the exergy of fuel utilized for the evaporation of water in each chamber of DGHS is indicated in Figure 4. At the initial chambers of the stenter, the specific costs are lower due to the higher evaporation rates. The constant rate period of drying have the lowest exergy costs. As the drying continues, the exergy costs increases significantly because the water content of the fabric decreases to a great extent and the drying rate slows down. It was calculated that the exergy costs of the stenter varies between 0.19 US\$/GJ and 0.59 US\$/GJ depending on the drying periods.

Figure 5 gives the exergy costs of DGHS and HOHS depending on the exhaust air humidity ratio. The exergy

costs were calculated for the DGHS and HOHS to be between 0.23 US\$/GJ to 0.26 US\$/GJ and 0.28 US\$/GJ to 0.30 US\$/GJ, respectively. It is quite clear that drying process in the HOHS leads to higher exergy costs compared with the DGHS. The primary heat generation for the HOHS occurs by the combustion of fuel in a separate hot oil boiler. The energy of the fuel is transferred to the hot oil indirectly which leads to a high exergy destruction. Additionally the hot oil heats the drying air indirectly by a heat exchanger. Due to the significant heat losses at the HOHS system, the fuel consumption and related exergy cost is high. As illustrated in Figure 6, the specific cost associated with the exergy of fuel utilized for the evaporation of water in HOHS is higher compared with the DGHS.

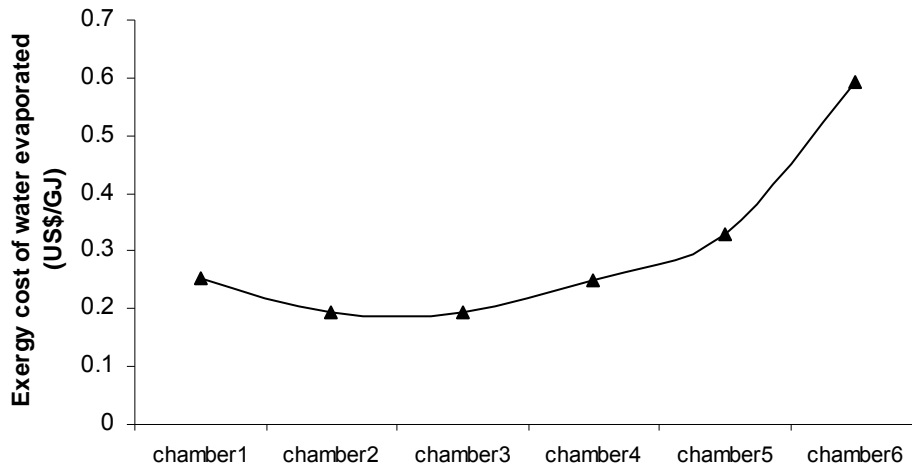


Figure 3. Exergy costs of water vapor evaporated in each chamber of the DGHS

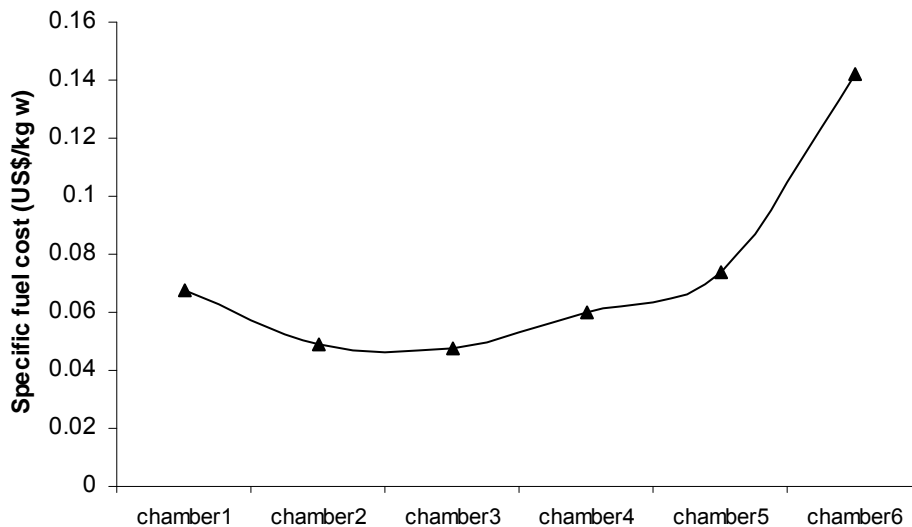


Figure 4. Specific cost associated with the exergy of fuel utilized for the evaporation of water in each chamber of the DGHS

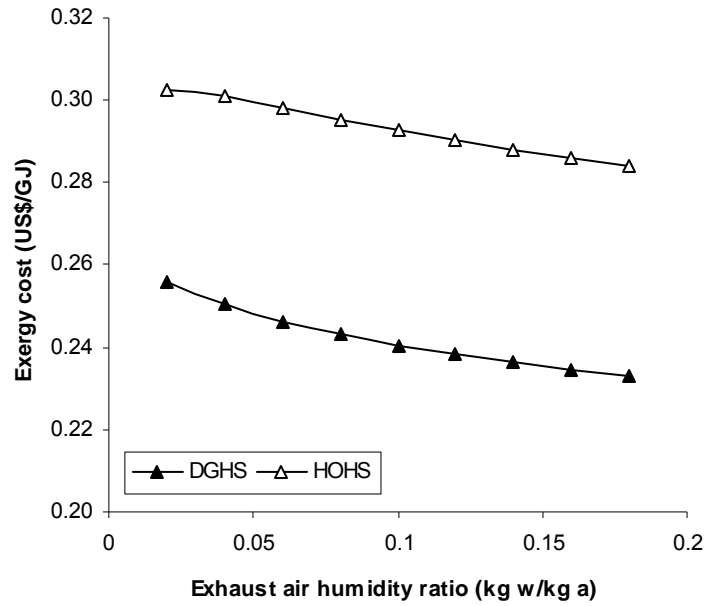


Figure 5. Exergy costs of the DGHS and HOHS depending on the exhaust air humidity ratio

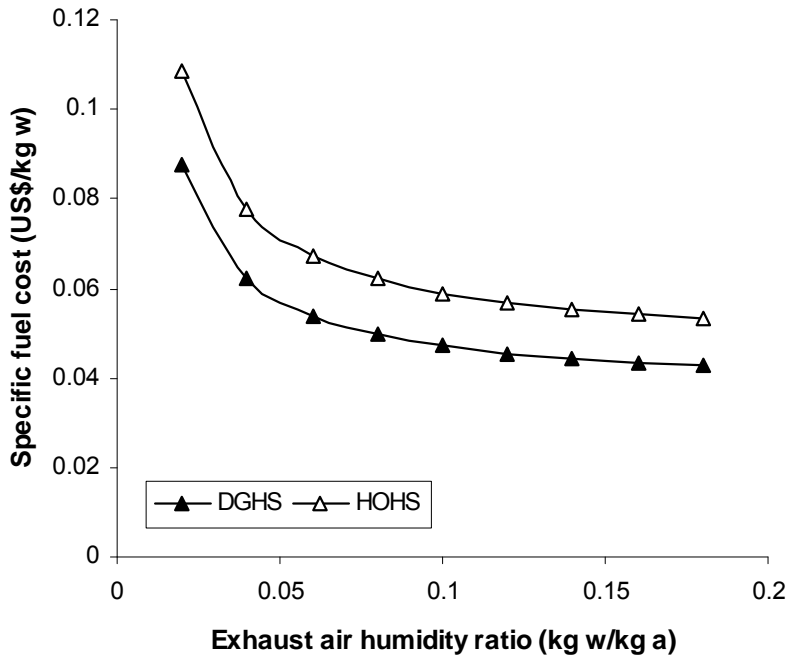


Figure 6. Specific costs associated with the exergy of fuel utilized for the evaporation of water at the DGHS and HOHS depending on the exhaust air humidity ratio

As conducted in Figures 5 and 6, the costs decrease with the increase in exhaust air humidity ratio. When considering exergy destruction and utilization rates, it was concluded that these data did not show a significant change after a certain value of the exhaust air humidity ratio. However, in exergy cost study, it was investigated that there is a linear relationship between the exergy costs and exhaust air humidity ratio. Thus increase in the

exhaust air humidity ratio to the possible highest value is a vital factor for textile drying.

Figures 7 and 8 represent the exergy costs and specific costs associated with the exergy of fuel utilized in DGHS depending on the residual moisture content of the fabric outlet, respectively. Excessive drying leads to a decrease in the drying rate, thus the exergy utilization for drying increases. Especially, in the last chambers of the

stenter in which the excessive drying occurs, the specific energy required for the evaporation of the water reaches its highest value. On this account, drying of the fabrics to residual moisture content lower than its natural hygroscopic moisture content increases the exergy costs to a great extent. It was investigated that there is a linear relationship between the exergy costs and residual moisture content of the fabric outlet.

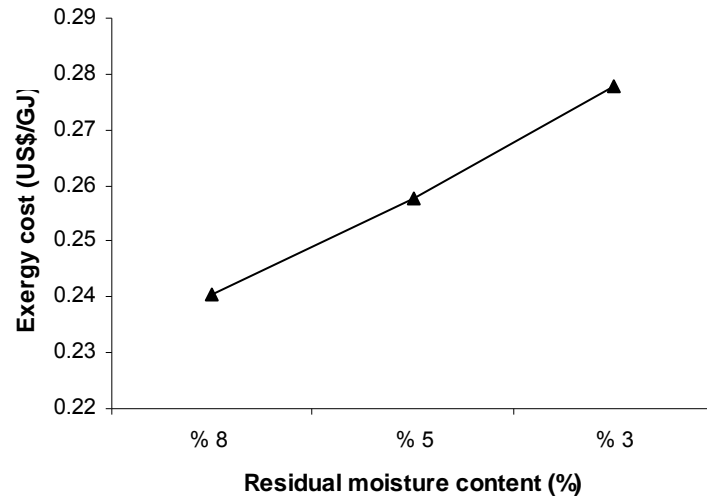


Figure 7. Exergy costs of the DGHS depending on the residual moisture content of fabric outlet

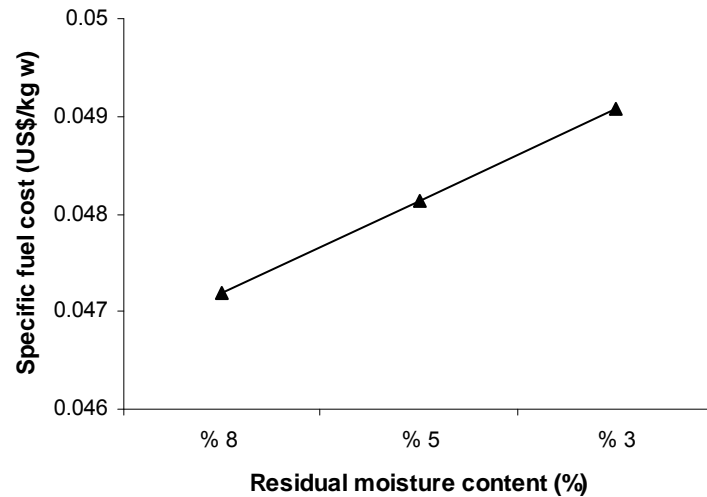


Figure 8. Specific costs associated with the exergy of fuel utilized for the evaporation of water at the DGHS depending on the residual moisture content of fabric outlet

4. CONCLUSIONS

This study investigated the exergo-economic analysis of stenters by using SPECO method. For this purpose, the cost rate balances and auxiliary thermoeconomic relations were developed for each sub-component of the DGHS and HOHS. The target exergy cost was selected to be the exergy costs of the water evaporated.

The main conclusions drawn from the results of the present study may be listed as follows:

a) The constant-rate period of drying shows the lowest exergy costs. It was calculated that the exergy costs of the stenter varied between 0.19 US\$/GJ and 0.59 US\$/GJ depending on the drying periods.

b) The exergy costs were linearly influenced by the exhaust air humidity ratio and the residual moisture content of the fabric outlet. The higher the exhaust air humidity and residual moisture content, the lower the exergy costs.

c) The exergy costs of the DGHS and HOHS were calculated to vary from 0.23 US\$/GJ to 0.26 US\$/GJ and from 0.28 US\$/GJ to 0.30 US\$/GJ, respectively; depending on the exhaust air humidity ratio.

d) For a future study, it is recommended to conduct (i) a comparative study on textile dryers using various types of exergoeconomic analysis methods and (ii) exergoenvironmental

analysis and assessment of textile dryers.

NOMENCLATURE

\dot{C}	cost rate (US\$/s)
c	exergy cost (US\$/GJ)
ex	specific exergy (kJ/kg)
$\dot{E}x$	exergy rate (kW)
h	specific enthalpy (kJ/kg)
\dot{m}	mass flow rate (kg/s)
s	specific entropy (kJ/kgK)
T	temperature ($^{\circ}$ C or K)
\dot{W}	work rate or power (kW)
\dot{Z}	annualized cost rate of the equipment (US\$/s)

DGHS direct gas heated stenter
HOHS hot oil heated stenter
SPECO specific exergy costing

Subscripts

a air
 e exit
 i inlet
 q heat transfer related
 w water

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